Measurement of Relative Cross-Section of ν_τ to ν_e

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Relative Cross Section

The number of observed ν_τ interactions is calculated using

$$N_{\nu_\tau}^{\text{obs}} = \int N_{\nu_\tau}^{\text{on tar}}(E) \cdot \epsilon_{\nu_\tau} \cdot \sigma_{\nu_\tau}^{cc}(E) \cdot n \cdot dE \quad (1)$$

where $N_{\nu_\tau}^{\text{obs}}$ is the number of ν_τ interactions observed, $N_{\nu_\tau}^{\text{on tar}}(E)$ is the number of ν_τ's that traverse the target, ϵ_{ν_τ} is the total efficiency, $\sigma_{\nu_\tau}^{cc}(E)$ is the cross section of the ν_τ, and n is the number of scattering centers per cm^2 in the target.

To calculate the relative cross section, use the following equation:

$$\frac{N_{\nu_\tau}^{\text{obs}}}{N_{\nu_e}^{\text{obs}}} = \frac{\int N_{\nu_\tau}^{\text{on tar}}(E) \cdot \epsilon_{\nu_\tau} \cdot \sigma_{\nu_\tau}^{cc}(E) \cdot n \cdot dE}{\int N_{\nu_e}^{\text{on tar}}(E) \cdot \epsilon_{\nu_e} \cdot \sigma_{\nu_e}^{cc}(E) \cdot n \cdot dE} \quad (2)$$

I use ν_e because all are prompt. Since n is the same regardless of the neutrino type, it cancels.

The charged current cross section for ν_e at the typical energies in this experiment is assumed to be linear in energy:

$$\sigma_{\nu_e}^{cc}(E) = E_{\nu_e} \cdot \sigma_{\nu_e \text{ const}}^{cc} \qquad (3)$$

where E_{ν_e} is the energy of the ν_e and $\sigma_{\nu_e \text{ const}}^{cc}$ is the constant part of the cross section. The cross section for the ν_τ can be written in terms of the ν_e cross section:

$$\sigma_{\nu_\tau}^{cc}(E) = K_F(E) \cdot \sigma_{\nu_e}^{cc}(E) \qquad (4)$$

where $K_F(E)$ is a kinematic term necessary because of the mass of the tau.

Equations 3 and 4 can be combined:

$$\sigma_{\nu_\tau}^{cc}(E) = K_F(E) \cdot E_{\nu_\tau} \cdot \sigma_{\nu_\tau \text{ const}}^{cc} \qquad (5)$$

If the ν_τ is a standard model particle, then:

$$\sigma_{\nu_e \text{ const}}^{cc} = \sigma_{\nu_\tau \text{ const}}^{cc} \qquad (6)$$

Substituting equations 3 and 5 into 2:

$$\frac{N_{\nu_\tau}^{\text{obs}}}{N_{\nu_e}^{\text{obs}}} = \frac{\int N_{\nu_\tau}^{\text{on tar}}(E) \cdot \epsilon_{\nu_\tau} \cdot K_F(E) \cdot E_{\nu_\tau} \cdot \sigma_{\nu_\tau}^{cc} \text{ const} \cdot dE}{\int N_{\nu_e}^{\text{on tar}}(E) \cdot \epsilon_{\nu_e} \cdot E_{\nu_e} \cdot \sigma_{\nu_e}^{cc} \text{ const} \cdot dE} \tag{7}$$

Simplifying this equation:

$$\frac{N_{\nu_\tau}^{\text{obs}}}{N_{\nu_e}^{\text{obs}}} = \frac{\epsilon_{\nu_\tau} \cdot \sigma_{\nu_\tau}^{cc} \text{ const} \cdot \int N_{\nu_\tau}^{\text{on tar}}(E) \cdot K_F(E) \cdot E_{\nu_\tau} \cdot dE}{\epsilon_{\nu_e} \cdot \sigma_{\nu_e}^{cc} \text{ const} \cdot \int N_{\nu_e}^{\text{on tar}}(E) \cdot E_{\nu_e} \cdot dE} \tag{8}$$

Solving for $\sigma_{\nu_\tau}^{cc}$ const:

$$\sigma_{\nu_\tau}^{cc} \text{ const} = \frac{N_{\nu_\tau}^{\text{obs}} \cdot \epsilon_{\nu_e} \sigma_{\nu_e}^{cc} \text{ const} \int N_{\nu_e}^{\text{on tar}}(E) E_{\nu_e} dE}{N_{\nu_e}^{\text{obs}} \cdot \epsilon_{\nu_\tau} \int N_{\nu_\tau}^{\text{on tar}}(E) K_F(E) E_{\nu_\tau} dE} \tag{9}$$

Calculating Parameters

- Observed Number of Neutrino Interaction

  This number comes from the data and the parameter analysis. Currently (subject to change) the observed numbers are:

  $$N_{\nu_\tau}^{\text{obs}} = 6 \pm 2.45 \qquad (10)$$

  and

  $$N_{\nu_e}^{\text{obs}} = 160 \pm 13.3 \qquad (11)$$

- Constant Part of ν Charged Current Cross Section

  The measured value for equal parts ν and $\overline{\nu}$ is:

  $$\sigma^{cc}(\nu N)/E = 0.505 \pm 0.009 \times 10^{-38} cm^2 GeV^{-1} \qquad (12)$$

  which is measured from data for the ν_μ (pdg).

Calculating Parameters Cont.

- Efficiency

The necessary efficiencies are: ν_e , $\nu_{\tau \text{ kink}}$, and $\nu_{\tau \text{ trident}}$. Each efficiency is the product of the trigger and the selection, which I took from Jason's thesis. The identification efficiencies are also necessary - I discuss each case below.

The identification efficiency for the ν_τ relates to the cuts applied:

Criterion	Efficiency (%)
Decay Length	68
Decay Angle	84
Daughter IP	97
Daughter P	96
Daughter P$_t$	78

Jason used Monte Carlo and found total ϵ for single-prong tau decays to be 38%.

For the trident, the identification efficiency only relates to the decay length (as this is the only cut?). The tau must have at least one emulsion segment (76%) and be less than 10 mm (90%). This leads to an identification efficiency of 68% and a total ϵ of 52%.

The identification efficiency I used for the electron is 73%. This should be a combination of electron ID in the spectrometer and the emulsion - still working on this number.

The efficiencies are summarized in the following table:

Efficiencies (%)			
Type	ν_τ kink cc	ν_τ trident cc	ν_e cc
Trigger	97	97	98
Selection	80	80	80
Identification	52	68	73
Total	38	52	57
Location?			
Parameter?			

- Number of ν that Traverse the Target

The number of νs that hit the target is :

$$N_\nu^{\text{target}}(E) = N_\nu^{\text{prod}} \cdot \frac{dN}{dE} \cdot \eta_\nu \qquad (13)$$

where $\frac{dN}{dE}$ is the energy spectrum of the produced neutrinos, η is the target angular acceptance, which is (Reinhard):

η_{ν_e}	0.068
η_{ν_τ}	0.067

and the number of neutrinos produced, N_ν^{prod} is:

$$N_\nu^{\text{prod}} = \sum_j \sigma(pN \to C_j X) BR(C_j \to \nu X) \qquad (14)$$

where $C_{i,(j)}$ are the relevant charm particles that produce ν_τ's (ν_e's), $\sigma(pN \to C_{i,(j)}X)$ are the charm production cross sections for 800 GeV protons, $BR(C_{i,(j)} \to \nu_\tau X)$ is the branching ratio for these charm particles to $\nu_\tau + X$ ($\nu_e + X$). C_i can be D_s or $D^\pm$; C_j can be D_s, $D^\pm$, D^0, or Λ_c.
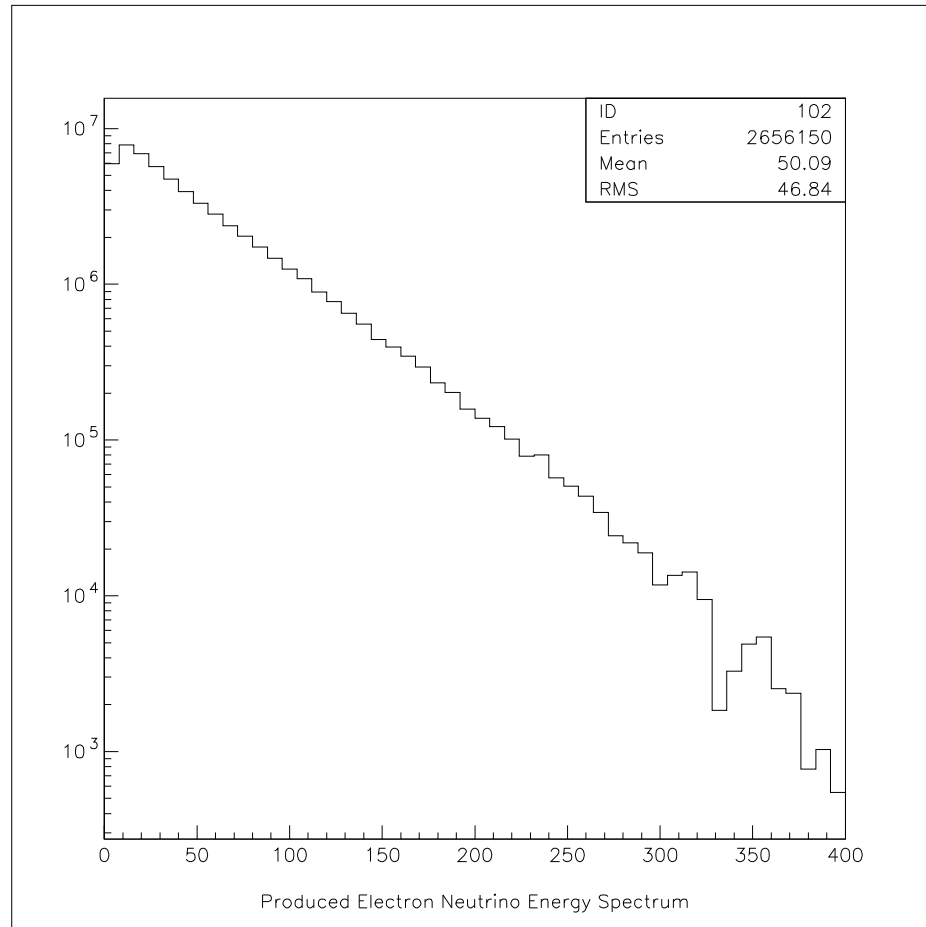
Since we are interested in the ratio, we can use the following equation:

$$\frac{N_{\nu_\tau}^{\text{prod}}}{N_{\nu_e}^{\text{prod}}} = \frac{\sum_j \sigma(pN \to C_j X) BR(C_j \to \nu_\tau X)}{\sum_i \sigma(pN \to C_i X) BR(C_i \to \nu_e X)} \tag{15}$$

800 GeV Production CS	
in μbarn/nucleon (Reinhard)	
$\sigma(pN \to D_s X)$	5.2 ± 0.8
$\sigma(pN \to D^\pm X)$	11.3 ± 2.2
$\sigma(pN \to D^0 X)$	27.4 ± 2.6
$\sigma(pN \to \Lambda_c X)$	5.4 ± 2.1

Branching ratios (pdg)	
$BR(D_s \to \nu_e X)$	8 ± 5.5 %
$BR(D_s \to \nu_\tau X)$	6.4 ± 1.5 %
$BR(D^\pm \to \nu_e X)$	17.2 ± 1.9 %
$BR(D^\pm \to \nu_\tau X)$	7.2×10^{-4}
$BR(D^0 \to \nu_e X)$	6.9 ± 0.3 %
$BR(\tau \to \nu_e X)$	7.8 ± 0.06 %
$BR(\Lambda_c \to \nu_e X)$	2.1 ± 0.6 %

$\dfrac{dN_{\nu_e}}{dE}$ and $\dfrac{dN_{\nu_\tau}}{dE}$ are the energy spectra of the produced ν_e and ν_τ. I produced these distributions using the E872 MC:
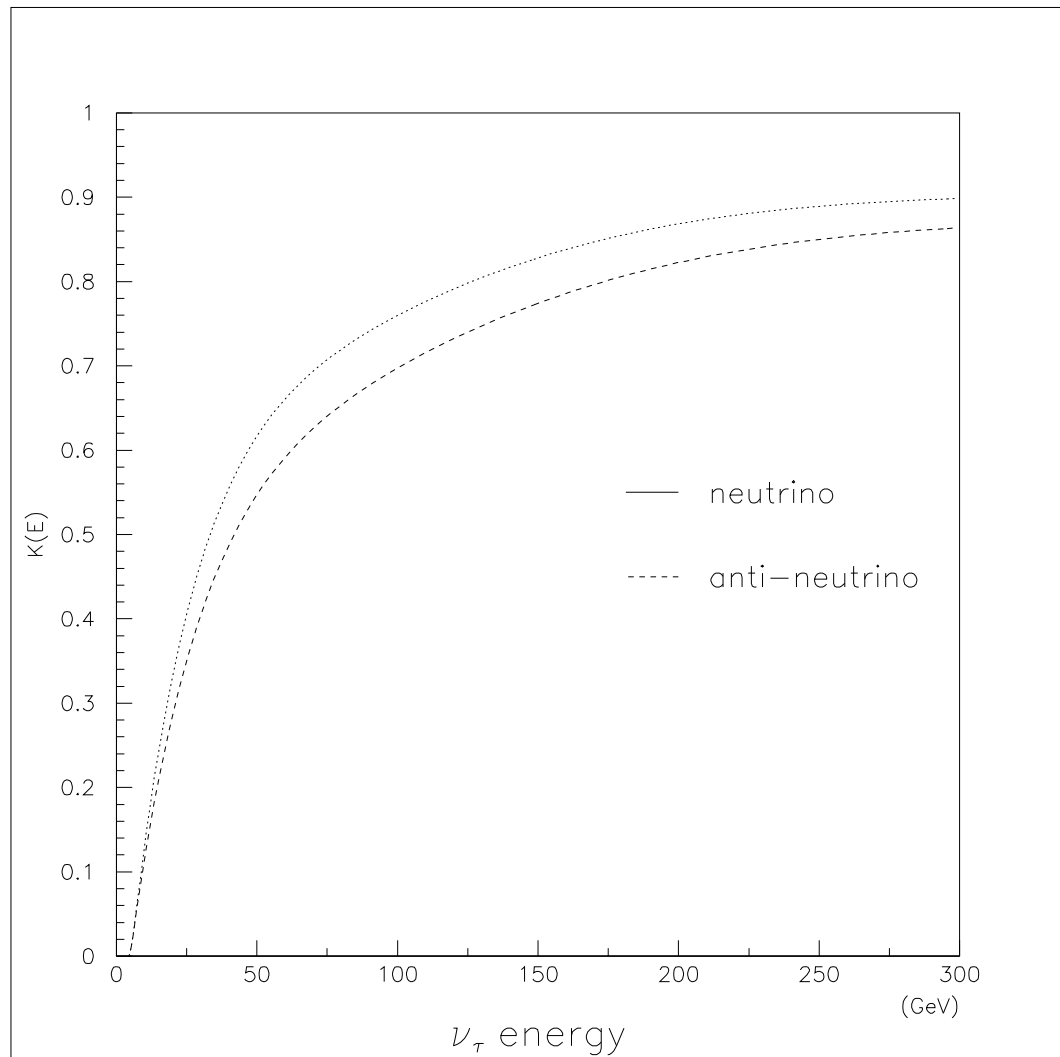

ID	102
Entries	2656150
Mean	50.09
RMS	46.84

Produced Electron Neutrino Energy Spectrum

The energy spectrum of the produced ν_e.
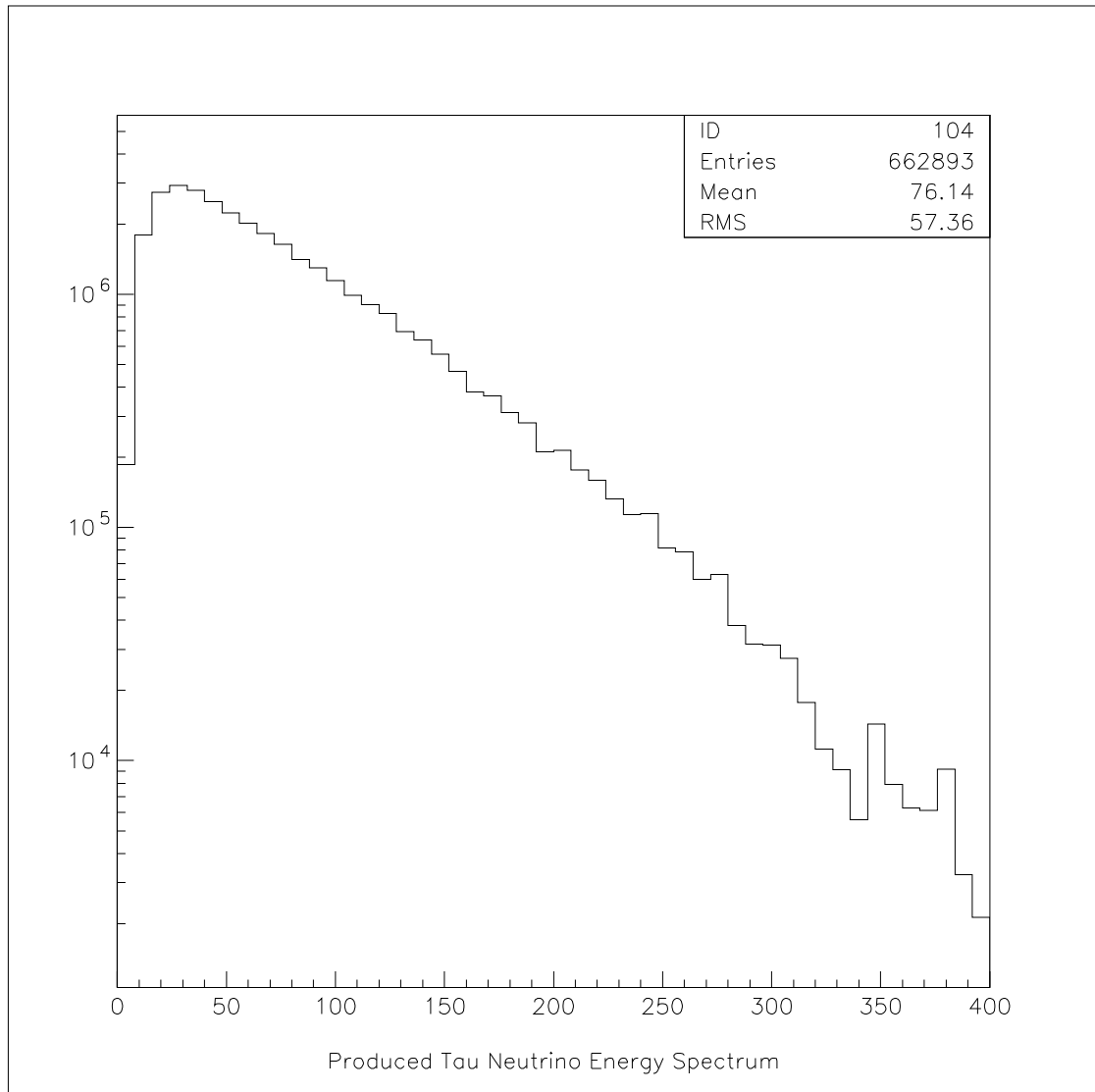
The energy spectrum of the produced ν_τ.

- **Kinematic Factor**

Calculated using the differential cross section of Albright and Jarlskog (Nucl. Phys. B40, 85 (1995)).

- Energy Dependence

The constant part of the ν_τ cross section, $\sigma^{cc}_{\nu_\tau \text{ const}}$, is:

$$\frac{N^{\text{obs}}_{\nu_\tau} \cdot \epsilon_{\nu_e} \cdot \sigma^{cc}_{\nu_e \text{ const}} \cdot N_{\nu_e} \cdot \int E_{\nu_e} \cdot \dfrac{dN_{\nu_e}}{dE} \cdot dE}{N^{\text{obs}}_{\nu_e} \cdot \epsilon_{\nu_\tau} \cdot N_{\nu_\tau} \cdot \int K_F(E) \cdot E_{\nu_\tau} \cdot \dfrac{dN_{\nu_\tau}}{dE} \cdot dE} \tag{16}$$

Using numerical integration:

$$\frac{\int E_{\nu_e} \cdot \dfrac{dN_{\nu_e}}{dE} \cdot dE}{\int K_F(E) \cdot E_{\nu_\tau} \cdot \dfrac{dN_{\nu_\tau}}{dE} \cdot dE} = 0.948 \tag{17}$$

Using this equation and the parameters summarized below:

$$\frac{N_{\nu_\tau}^{\text{obs}} \cdot \epsilon_{\nu_e} \cdot \sigma_{\nu_e}^{cc} \text{ const} \cdot N_{\nu_e} \cdot \int E_{\nu_e} \cdot \frac{dN_{\nu_e}}{dE} \cdot dE}{N_{\nu_e}^{\text{obs}} \cdot \epsilon_{\nu_\tau} \cdot N_{\nu_\tau} \cdot \int K_F(E) \cdot E_{\nu_\tau} \cdot \frac{dN_{\nu_\tau}}{dE} \cdot dE} \quad (18)$$

Parameter	ν_e value	ν_τ value
N_ν^{obs}	160 ± 13.3	6 ± 2.45
ϵ_ν	0.42	0.33
N_ν	4.41 ± 2.57	0.682 ± 0.232

$$\sigma^{cc}(\nu N)/E = 0.505 \pm 0.009 \times 10^{-38} cm^2 GeV^{-1}$$

$$\frac{\int E_{\nu_e} \cdot \frac{dN_{\nu_e}}{dE} \cdot dE}{\int K_F(E) \cdot E_{\nu_\tau} \cdot \frac{dN_{\nu_\tau}}{dE} \cdot dE} = 0.948$$

$$\sigma_{\nu_\tau} \text{const} = 0.158 \pm 0.126 \times 10^{-38} cm^2 GeV^{-1}$$
$$(19)$$

Since we would expect this number to be closer to 0.505, what could cause it to be low?

- Efficiencies?

  If the total efficiency for the electron is underestimated or the tau efficiency is over estimated

- Number of observed events?

  If the number of taus is low or (more likely) the number of electrons is high

- Energy dependence?

  If there is a problem with my calculation of the energy dependence

  Patrick also calculated this, are the results consistent?

Patrick's value is the ratio of ν_τ to prompt ν $(\nu_e + \nu_\mu + \nu_\tau)$:

$$\frac{\int E_{\nu_{\text{prompt}}} \cdot \dfrac{dN_{\nu_{\text{prompt}}}}{dE} \cdot dE}{\int K_F(E) \cdot E_{\nu_\tau} \cdot \dfrac{dN_{\nu_\tau}}{dE} \cdot dE} = 0.69 \quad (20)$$

My value is: $\dfrac{\int E_{\nu_e} \cdot \dfrac{dN_{\nu_e}}{dE} \cdot dE}{\int K_F(E) \cdot E_{\nu_\tau} \cdot \dfrac{dN_{\nu_\tau}}{dE} \cdot dE} = 0.948$

If you make the assumption that

$$\int E_{\nu_e} \cdot \frac{dN_{\nu_e}}{dE} \cdot dE = \int E_{\nu_\mu} \cdot \frac{dN_{\nu_\mu}}{dE} \cdot dE \quad (21)$$

One can solve for ν_e/ν_τ using Patrick's value. The result is:

$$\frac{\int E_{\nu_e} \cdot \dfrac{dN_{\nu_e}}{dE} \cdot dE}{\int K_F(E) \cdot E_{\nu_\tau} \cdot \dfrac{dN_{\nu_\tau}}{dE} \cdot dE} = 0.23 \quad (22)$$

Conclusions

- Further investigate efficiencies, particle ID, and produced neutrino energy spectra.